Frontiers in High Energy Density Physics: The view from astrophysics

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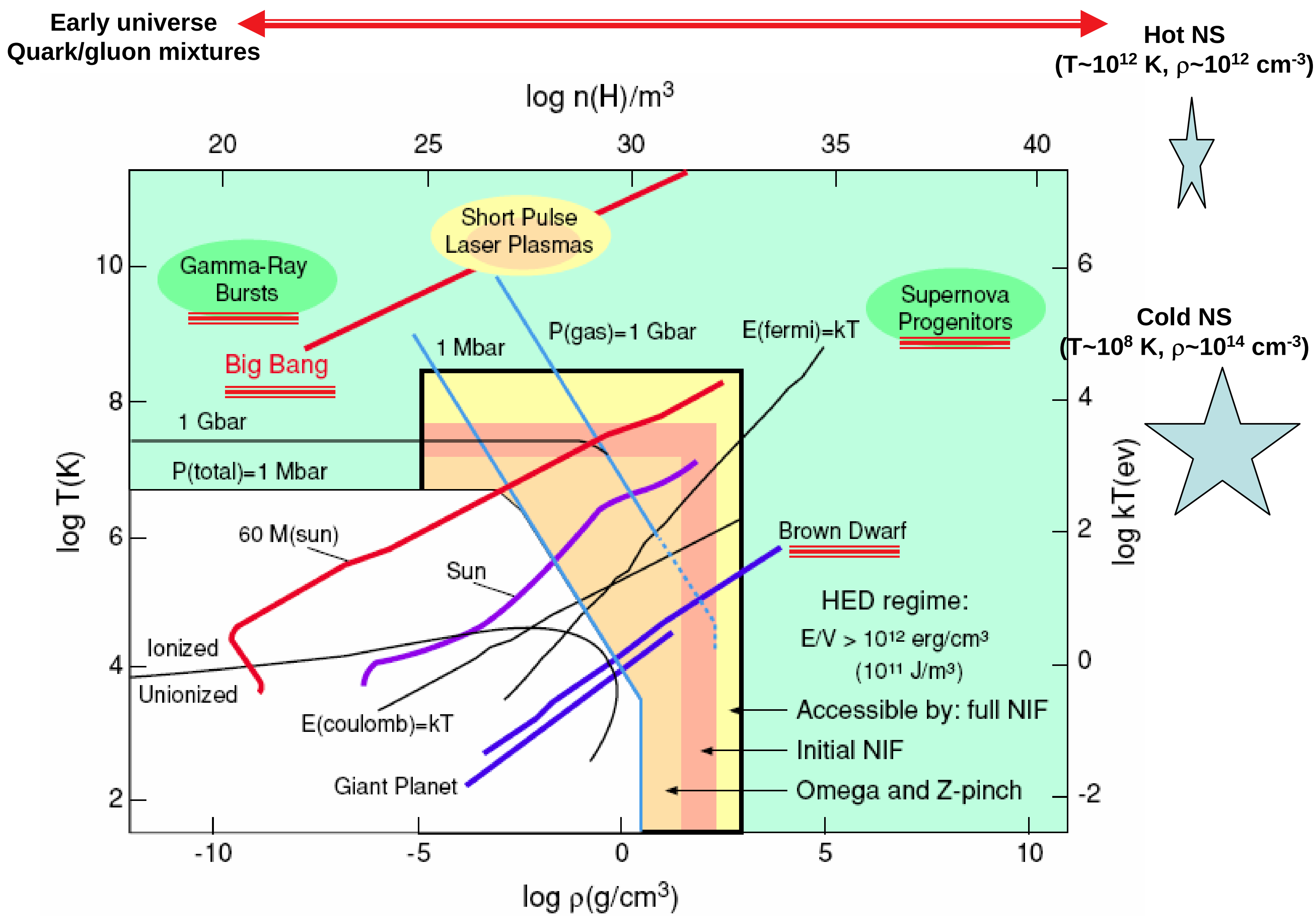
To begin with - the status of HEDP in astrophysics

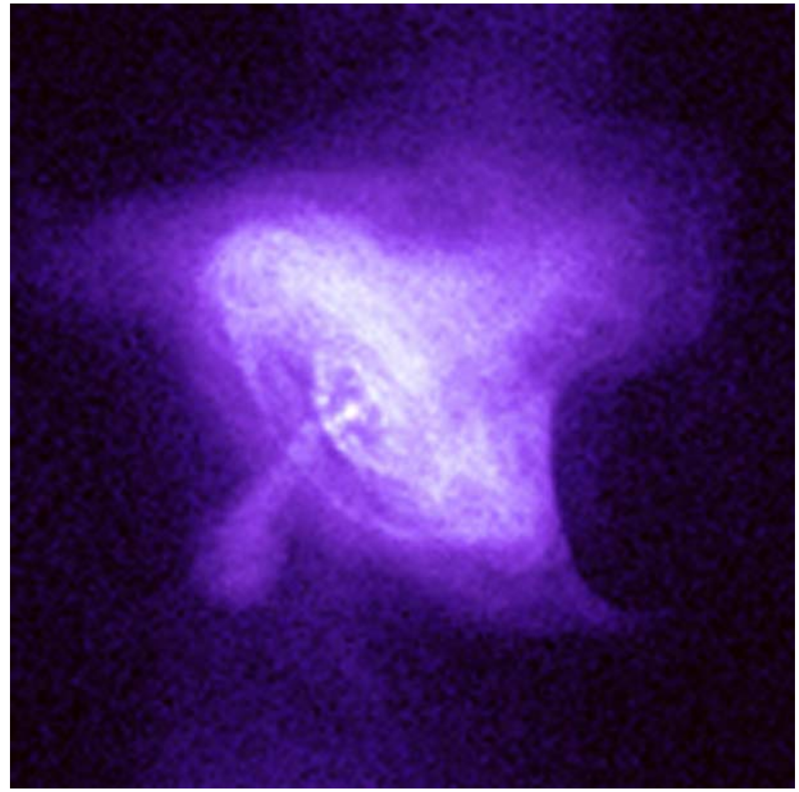
- HEDP is a well-recognized discipline in astrophysics
  - HEDP has in large part emerged from astrophysics
    - S. Chandrasekhar's work on the EOS of white dwarfs … ApJ, 74, 81-82
- The connections to the laboratory are both
  - "traditional": Nevada test site …
  - "recent": Nova/LLNL, Omega/Rochester, Z-pinch/Sandia, Nike/NRL, …, NIF/LLNL
- The level of enthusiasm is great, especially for exploiting the connections to the laboratory - but the sponsors are not as yet plentiful …

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Where does HEDP enter in astrophysics?



A by-now classic example …



The Crab Nebula: a view in the optical (left; HST/NASA) and in X-rays (right; Chandra/NASA)

The “big questions” for HED astrophysics

- *How does matter behave under conditions of extreme temperature, pressure and density?*
  - Origin and evolution of giant planets and brown dwarfs
  - EOS, opacities, conductivity, diffusivity, viscosity, … , of stellar matter
  - Basic physics of degenerate plasmas (e.g., convection, URCA, …)
  - Nuclear burning: ignition? transition from flame to detonation?
  - Quark-gluon plasmas/the very early universe, strongly coupled plasmas
  - UHECR: origins? composition? propagation?
  - …
- *How does matter interact with photons and neutrinos under extreme conditions?*
  - Accreting black holes/neutron stars: disks, jets, …
  - Gamma ray bursters
  - Pair plasmas
  - …

The astrophysics "thrust areas": preface

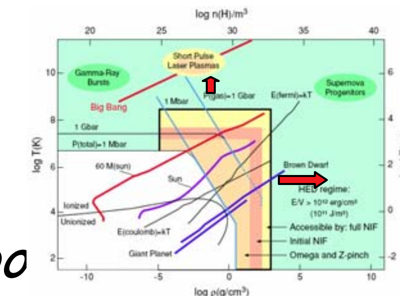
- Scope of possible "thrust areas" by "venue" is overwhelmingly large
  - Conclusion: we need to find a different way of thinking about "thrust areas" for astrophysics
- What differentiates HED astrophysics is the way the science is carried out
  - Virtually all astrophysical data is obtained via remote sensing
  - "Experiments" in the traditional physics mode are not possible

The thrust areas

- Astrophysical phenomena: <u>Modeling</u>
  - The use of existing physics theory (or extrapolations of existing theory) to build models describing particular phenomena: "astroengineering"
- Astrophysical basic theory: <u>Fundamental physics</u>
  - Studies of the fundamental physical processes governing matter and radiation under HED conditions
- Astrophysical laboratory studies: <u>HEDLA</u>
  - Measurement of fundamental material properties
  - Exploration of astrophysical phenomenology under controlled lab conditions, to build intuition
  - Direct connections to astrophysical phenomena via scaling
  - Validation of instruments, diagnostics, simulations …

“Compelling question” #1 for HEDLA

- *What are the limits of our ability to test astrophysical models/fundamental physics in the laboratory?*
  - *What physics limits the boundaries that now define the attainable (n,T,p) conditions in the laboratory (e.g., via NIF, z-pinch, relativistic heavy ion beams, …)?*



  - *Is mhd turbulence achievable in the labo … HED conditions? Can we use laboratory data to develop an mhd “subgrid” model?*
  - *Can laboratory experiments help us devise more accurate models for radiation hydrodynamics*
    - *Beyond flux-limited diffusion, but shy of Boltzmann?*

"Compelling question" #2 for HEDLA

- *What are the limits to our ability to use scaling to connect the lab to simulations and astrophysics?*
  - *With a few crucial exceptions, the dimensionless control parameters for astrophysics are, by and large, unattainable in the laboratory (or in simulations)*
  - *One crucial class of exceptions arise in hydrodynamics:*
    - *Fluid Reynolds number: 10^6-10^7 easily attainable in lab*
    - *Rayleigh number for convecting systems: 10^{14} attainable in lab*
  - *The central question: what is lost when extrapolating from the lab regimes to astrophysics (viz., assuming that viscosity is negligible for both the lab and the astrophysics)?*
    - *Nusselt-Rayleigh scaling for Boussinesq convection suggests caution …*

“Compelling question” #3 for HEDLA

- *How can we use laboratory experiments to elucidate either fundamental physics or phenomenology of astrophysical systems that are as yet inaccessible to either theory or simulations?*
  - Turbulent accretion disks?
  - High Mach number jets?
  - …
    - The problem of scaling …
    - The problem of lab-related new physics …
      - Magnetorotational instabilities vs. Ekmann flows

... which brings us to

Comments and questions